Structure, Innovation and Consumer Welfare: Agricultural Biotech

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Abstract:

Since 1995, the outstanding feature of the agricultural biotech industry structure is its increasing concentration, accomplished primarily through mergers and acquisitions (M&A). Kalaitzandonakes (1999) describes the M&A activity as following a cyclical pattern, with peaks from 1988-92 and 1996-97 and a valley from 1993-95. In separate work Brennan, Pray and Courtmanche (1999) examine industry concentration and its relationship with U.S., plant, biotech, field-trial activity by large and small firms. Comparative analysis shows that the ratio of large-firm (four largest firms) to small-firm (other firms) field trials, and the Herfindahl-Hirshmann concentration index, move pro-cyclically with M&A activity.

This paper provides an innovative theoretical model of small- and large-firm R&D activity. The model generates cyclical patterns of behavior, which emerge as the outcome of endogenous R&D investment decisions. The model generalizes earlier theoretical work by Oehmke et al., who model R&D and industry concentration cycles as the result of unanticipated changes in the costs of R&D and/or in the profits earned from successful innovation. In addition to providing a more general market framework, this paper extends the models to the case in which a single shock can affect the profit levels of both small and large innovators.

The main result in this paper is that unanticipated changes in innovator profits can generate cyclical patterns in the level of large-firm R&D activity relative to small-firm R&D activity. Numerical solutions to the dynamic equilibrium conditions exhibit the same patterns of R&D behavior as are observed empirically. In particular, the model generates ratios of small/large-firm R&D activity which are consistent with evidence on number of genetically-modified-crop field trials. Previous work in this area has not successfully modeled this ratio.

The policy implication is that existing data are insufficient to show that biotech concentration, is negatively affecting the R&D investment of small firms.

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1. INTRODUCTION

Since 1995, the outstanding feature of the agricultural biotech industry structure is its increasing concentration, accomplished primarily through mergers and acquisitions (M&A). Kalaitzandonakes (1999) describes the M&A activity as following a cyclical pattern, with peaks from 1988-92 and 1996-97 and a valley from 1993-95 (Figure 1). In separate work Brennan, Pray and Courtmanche (1999) examine industry concentration and its relationship with U.S., plant, biotech, field-trial activity by large and small firms. Comparative analysis shows that the ratio of large-firm (four largest firms) to small-firm (other firms) field trials, and the Herfindahl-Hirshmann concentration index, move pro-cyclically with M&A activity (Figure 1).

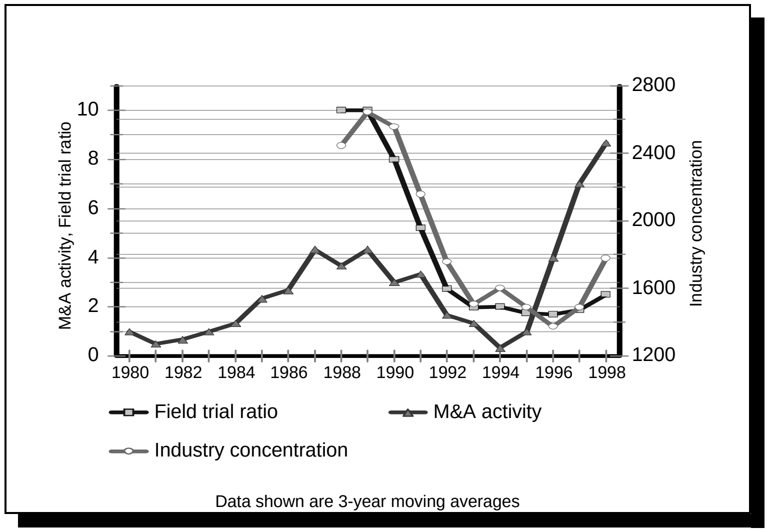

Figure 1. Patterns of cyclical behavior in biotech M&A activity, industry concentration, and ratio of large:small firm GMO field trials.

Sources; M&A activity calculated from Kalaitzandonakes, field trial ratio and industry concentration from Brennan, Pray and Courtmanche.

This contribution of this paper is the development of a model that examines the relationship between consumers and the agricultural biotech R&D and industry concentration cycles. Of particular interest are the relationships among R&D activity by large and small firms, industry concentration, and consumer welfare.

Consumers are involved in the R&D-cycle model in two fashions. First, following Oehmke et al., the driving force behind these cyclical patterns of M&A and R&D activity is consumer non-acceptance of agricultural biotech products. Consumer non-acceptance, particularly in the European Union (EU), causes realized firm profits to be significantly lower than expected profits, particularly for large, multinational firms. In aggregate, large firms react by reducing R&D activity, which increases industry concentration. Moreover, large firms are likely to over-react and reduce R&D activity below the new steady-state levels, leading to cyclical patterns of R&D activity and industry concentration. In contrast, SMURFs may make a smoother transition to the new steady state. This creates disparate R&D behavior between large firms and SMURFs, leading to patterns similarly to those found empirically (Figure 1).

The second way in which consumers are involved in this model is that consumer welfare may be affected by agricultural biotech industry structure. In particular, Brennan, Pray and Courtmanche question whether increases in industry concentration and accompanying acquisitions of small firms restrict R&D and subsequently slow the rate of innovation and welfare growth. *Prima facie* empirical evidence in support of this hypothesis is found by comparing the number of US field trials of genetically modified crops by the four largest firms (in terms of number of field trials) with the remaining (small/medium) firms (Figure 2). This comparison shows that when industry concentration was decreasing (1991-1994) the number of small/medium trials increased. From 1995-1998 industry concentration was increasing, and even though the aggregate number of trials increased, the number conducted by small/medium firms decreased.

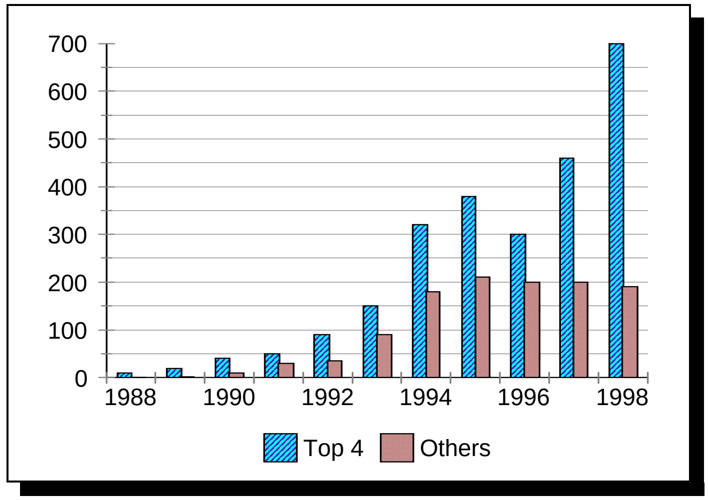

Figure 2. Number of U.S. transgenic plant field trials, by top 4 firms and all other firms, 1988-1998.

Source: Brennan, Pray and Courtmanche.

Anticipating the results, this paper suggests that the small/medium firm R&D behavior could simply be a smooth transition to a lower level of R&D activity, which is consistent with lowered profit expectations. The lower R&D level and the transition path need not be caused by the increased concentration. In fact, the model allows no mechanism for large-firm industry concentration to affect the profit level of SMURFs (since they are targeting different markets). Is it then merely coincidence that the reduction in small/medium R&D activity occurs simultaneously with the increases in concentration? No, both the concentration cycle–driven by large-firm R&D activity–and the small/medium firm R&D levels are responses to the same stimulus: lowered profit expectations. Hence they can be expected to occur at the same time. However, this simultaneity need not be evidence of causality, and in fact the paper generates a contrary model of causality. The punch line is that if the proposed model is correct, then slower growth in small/medium firm R&D levels, subsequently slower innovation rates, and slower growth in consumer welfare, are all consequences of slow consumer acceptance of agricultural biotech products.

2. THE MODEL

The model generalizes earlier theoretical work by Oehmke et al., who model agricultural biotech industry concentration cycles, and small and medium university-related firms (SMURF) and large-firm R&D activity. R&D and industry-concentration cycles are the results of unanticipated changes in the costs of R&D and/or in the profits earned from successful innovation. In addition to providing for a more general market framework, this paper extends the Oehmke et al. models to the case in which a single shock can affect the profit levels of both SMURF and large-firm innovators. The model generates cyclical patterns of behavior, which emerge as the outcome of endogenous R&D investment decisions. However, even in the presence of common shocks, the SMURF and large-firm cycles exhibit different behavioral characteristics.

The model itself represents innovative activity. We view innovative activity as the behavior that leads to new discoveries or inventions. Field trials represent the outcomes of innovative activity, and verify that potential discoveries are in fact valuable innovations. Thus, we will need to make some interpretive assumptions when we relate the model results to the empirical data.

The basic structure of the model is similar to Oehmke et al. There are two types of firms, large firms and SMURFs. The two types of firms operate in related but different markets. Large firms operate in high-value markets, with the potential for high payoffs for successful innovation. SMURFs operate in low-value or niche markets.

Each firm engages in R&D in an attempt to discover the next innovation in their market. The R&D process is inherently uncertain, both as to the timing of the next innovation's occurrence, and as to which firm will be the innovator. The innovating firm in each market discovers and patents an improved quality product. The innovating firms earn rents because they are the only firms with the highest quality product.

The key distinction between large firms and SMURFs is in their costs of doing research. Large firms have high fixed costs, but low marginal costs. SMURFs are assumed to have no fixed costs, but their marginal costs are higher than those of large firms. Because of the fixed costs, there will be a range of outputs at which the average cost of large-firm research exceeds the average cost of small-firm research. For some products with limited profit potential, smaller levels of research activity will be optimal. Thus, SMURFs will focus on these markets, while large firms will focus on those markets with high profit potential and for which it is optimal to conduct large amounts of research.

2.1 The SMURF Industry

We represent the SMURF industry as a very simple competitive fringe. Each SMURF targets a niche market, and invests in R&D to innovate in that market. We assume that there are a large number of niche markets, and that SMURFs don't compete with one another over the same niche (that wouldn't be smurfy!). Each successfully innovating firm earns profits in its market niche. However, these profits decay over time at an exogenously given rate . This decay is attributable to changes in farming systems that make the innovation less relevant, adaptation of biotic stressors, and leakage of private intellectual property to the industry.

The value of a SMURF, which successfully innovates, is

$$V_j \quad \frac{\Pi_j}{r \quad \gamma}, \tag{1}$$

where $_j$ represents the profits earned from the innovation. Equation (5) is analogous to equation (3), except that in equation (5) the discount rate contains the exogenous decay parameter   rather than the endogenous probability of the next innovation, .

Since the SMURFs have constant marginal cost, the number of firms and the level of R&D activity of a typical firm are indeterminate. However, we can determine the aggregate level of R&D activity, R_j according to the zero profit condition

$$\Phi(R_j)\, V_j \quad \frac{R_j}{\delta_x} \tag{2}$$

This equation simply states that the expected value of industry participation in race j (at each instant during the race) equals the cost of participating in the race.

Equations (1), (2) and the definition of   determine the R&D intensity and firm value in the SMURF industry. Solving for the R&D intensity results in

$$R_{j\ 1} \qquad \frac{\delta\Pi_j}{r \quad \gamma} \quad A \tag{3}$$

When $_j$ is constant, then so is the SMURF-industry R&D intensity.

2.2 The Large-Firm Industry

The model of the large-firm industry is closely adapted from Oehmke et al. Large firms engage in R&D races to become the first firm to discover the next innovation. The successful firm discovers and patents the current innovation, and earns limited monopoly profits from this intellectual property. Immediately upon successful innovation, the next R&D race commences as firms try to discover the next innovation and replace the current market leader.

The costs of doing research are represented by the cost function

$$C(R_{k,i}) = F + \frac{R_{k,i}^{\alpha}}{\delta_L}, \tag{4}$$

where the subscript L represents large firms, $R_{k,i}$ is the level of R&D activity in race k by firm i (we reserve the use of the subscript j for SMURF-product races, and the subscript k for large-firm-product races). F represents fixed costs, and δ_L represents the productivity of the research process. The parameter $\alpha>1$ defines the curvature of the cost and marginal cost functions, higher values of α are associated with higher marginal costs.

The large-firm research cost function is U-shaped. Ignoring the integer problem, free entry into the R&D race means that each large firm will produce at the minimum of their average cost curve. Denoting the minimum value and point with a star,[1]

$$C^{*} = \left(\frac{\delta_L F}{\alpha - 1}\right)^{1/\alpha}, \qquad R_{k,i}^{*} = F\,\frac{\delta_L F}{\alpha - 1}. \tag{5}$$

The benefits of research are that research gives the firm a better chance of being the first to innovate. The probability of innovation is assumed to follow a Poison process, with parameter . Let $R_k \quad {}_{i} R_{k,i}$, and define $\Phi(R_{k,i}) \quad \frac{R_{k,i}}{A \; R_k}$. The parameter A defines the difficulty of research success: for a higher A, the same level of $R_{k,i}$ generates a lower probability of success.

The value of the firm that innovates successfully is

$$V_k \quad \frac{\Pi_k}{r \quad \Phi(R_{k\;1})} \tag{6}$$

where $_k$ is the profits earned by the firm who successfully discovers innovation k. The value of this firm equals the discounted value of profits, where the discount rate consists of the return on risk-free assets, r, plus a risk term equal to the probability that the next innovation will be discovered and the current innovator will lose its market power. We assume that $_k$ is sufficiently large so that firms invest non-zero amounts in R&D activities (this assumption is formalized later).

We assume that there is free entry into the R&D race. This leads to the zero-profit condition

$$\Phi(R_{k,i})\, V_k \quad \frac{C}{R_{k,i}} R_{k,i} \tag{7}$$

This equation states that the expected value of the large firm participating in race k equals the cost of participating in that race.

Equations (6), (7) and the definition of   determine the R&D intensity and firm value in the large-firm industry. The industry-level R&D intensity for innovation race k+1 is defined by

$$R_{k\ 1} \qquad \frac{A\ C\quad r\, R_k}{C\quad R_k\,(1\qquad r)\ \Pi_k\, R_{k,\,i}} \tag{8}$$

Equation (8) is in fact a law of motion for large-firm-industry R&D. We assume that $_{k}$ is sufficiently large so that equation (8) generates only positive R&D intensities.

2.3 Comparative Steady-State Analysis and Transitional Dynamics

We define the steady-state by the condition that the R&D levels are constant across races: $R_j=R_{j+1}$ and $R_k=R_{k+1}$. In order for a steady state to exist, we must also assume that profits are constant. For the SMURFs, equation (3) with constant profits defines the steady-state R&D intensity. In the large-firm industry, imposing the steady-state conditions on equation (8) and solving for R&D intensity results in

$$\begin{aligned} R_S &\qquad \frac{\delta_S\,\Pi_S}{r\qquad \gamma}\quad A \\ R_L &\qquad \frac{\Pi_L\, R\qquad A\ C\quad r}{C\quad (1\ \ r)} \end{aligned} \tag{9}$$

where the subscripts S and L denote steady-state values for SMURF and large-firm industries, respectively.

Comparative steady-state analysis shows:

$$
\begin{aligned}
R_S / A &< 0 \qquad & R_L / A &< 0 \\
R_S / \Pi_S &> 0 \qquad & R_L / \Pi_L &> 0 \\
R_S / \delta_S &> 0 \qquad & R_L / \delta_L &> 0
\end{aligned}
\tag{10}
$$

These results show that steady-state research levels are decreasing in A, which is the difficulty of discovering a new innovation; increasing in innovator profits; and increasing in the s, which represent research efficiency.

We can now examine the influence of consumers on steady-state and transitional R&D levels. We consider the case in which a shock negatively affects both large-firm and SMURF profits, but has a proportionately greater affect on large-firm profits. The motivation for this is the current situation with EU consumer attitudes towards transgenic foods. These attitudes negatively affect large-firm profits. For example, in 1990, "Monsanto executives believe[d] the combined sales and royalties [from bovine and porcine growth hormone and 13 other genetically engineered products] could approach $1 billion a year by the end of the decade" (Schneider, 1990). By 1998 the biotech 'traits' businesses had generated revenues of only $209 million, and current projections are for 2002 revenue of $760 million, all from the U.S. and Latin America (Monsanto, 1999). Although some of the 1990 overestimate is due to technological optimism, the bulk is due to the unpredicted consumer antipathy towards biotech foods. EU firm restrictions on the purchase of transgenic commodities have undoubtedly affected large firms who focus their R&D efforts on export crops such as corn, soybeans and wheat. EU consumer attitudes probably have a smaller effect on SMURFs, who are more likely to focus on a different set of crops, and less likely to have an international focus. Therefore, we represent this shock in the model as unanticipated changes in the profit levels for SMURFs and large firms, with the latter receiving a bigger shock.

The effects of these shocks will be to reduce steady-state levels of R&D activity for SMURFs and large firms, as shown in equation (10). The magnitude of these changes will depend on the relative effect of profits on steady-state R&D, which in turn depends on other model parameters, and the relative magnitude of the change in profits.

The transitional dynamics are of greater interest to the current situation. The SMURFs adjust their R&D activity to the lower profit expectations in the next available innovation race, so the transition dynamics are straightforward. However, the large-firm transition dynamics are more complicated. In particular, there is a feedback from the expected level of R&D activity in race k+2 to the R&D activity in race k+1, since the profits earned by the winner of race k+1 are limited by how quickly innovation k+2 is discovered.

The large-firm transitional dynamics are simulated for the parameter values r=0.1, A=40,000, δ_L=8, α=130, F=100,

Table 1. Large-firm transitional dynamics.

Innovation Race	Level of research activity	Probability of innovation per period	Estimated number of periods until innovation	Relative level of R&D activity	Number of large firms
k	54601.25		1.73	10.00	19.74
k+1	8243.28	0.17	5.85	1.51	2.98
k+2	30317.64	0.43	2.32	5.55	10.96
k+3	14378.22	0.26	3.78	2.63	5.20
k+4	23616.08	0.37	2.69	4.33	8.54
k+5	17372.34	0.30	3.30	3.18	6.28
k+6	21221.62	0.35	2.88	3.89	7.67
k+7	18698.71	0.32	3.14	3.42	6.76
k+8	20290.33	0.34	2.97	3.72	7.33
k+9	19260.95	0.33	3.08	3.53	6.96
k+10	19916.29	0.33	3.01	3.65	7.20
k+11	19494.81	0.33	3.05	3.57	7.05

and Π_k=10,000. The initial point is the steady state associated with these parameters. The steady-state R&D activity level a is 54,601, which we also represent as a relative level normalized to 10 (for later comparison with SMURFs) (Table 1). In the steady state there are approximately 20 large firms in the industry, and the expected duration of an innovation race is less than two years. We introduce a consumer acceptance shock which reduces steady-state profits to 4,000, or 40% of the previous level. While this is a severe shock, it is consistent with the previous discussion of Monsanto's expected and realized profits.

In reaction to the change in profits, the R&D activity in k+1 falls to 15% of the level in race k, and the number of firms involved falls to 3. In the next race, R&D levels rebound to 56% of the initial level, and the number of firms increases to 11. This pattern of decline and resurgence continues until the industry settles around the new steady-state levels of approximately 7 large firms and R&D activity at 37% of the initial level. In other words, industry concentration, number of firms

We are particularly interested in the pattern of co-movement between large-firm and SMURF levels of field trial activity presented in Figure 2. Recall that the model is one of innovative activity, and so we make translate the level of innovative activity predicted by the model into a level of field trial activity (which we view as a post-innovation verification activity). We have in mind an unarticulated function, which makes this translation, and satisfies two assumptions. First, the initial steady-state level of large-firm field trial activity is about ten times the level of SMURF field-trial activity. This is simply a scaling assumption to make the initial steady-state match up with the 1988-89 data. The second assumption is that there is some sort of 'ramping-up' effect associated with the onset of transgenic crop field trials. This is equivalent to assuming that there is a trend component in the function that relates innovative activity to transgenic field trial numbers, at least in the early stages when the first transgenic crops are emerging. The cyclical patterns of R&D activity then generate cyclical patterns of field crop activity centered around this ramping-up trend.

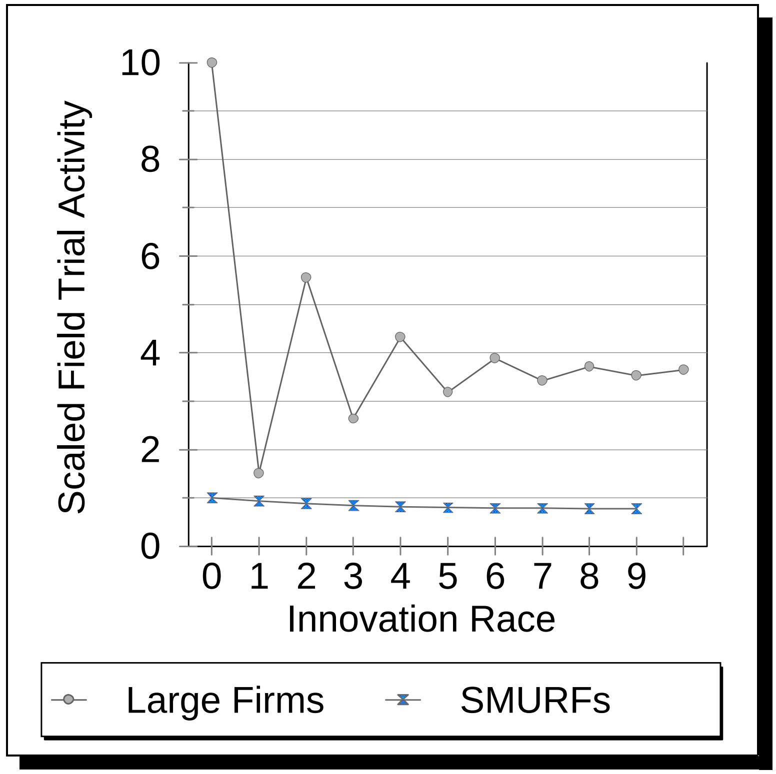

Figure 3. Simulation Results on Transitional R&D Activity Dynamics, Large Firms and SMURFs.

Source: author's calculations.

It is now possible to compare the levels of SMURF and large-firm field trial activity (Figure 3). In the initial period, race 0, the large firms conduct about ten times as many transgenic field trials as do the SMURFs. After the profit shock due to consumer non-acceptance of GMOs, both the SMURF and large-firm activity levels decline. The SMURF levels decline smoothly to the new steady-state (we allow for some adaptation of profit expectations), but the large-firm activity levels show the familiar cyclical pattern.

The relative large-firm activity level falls to about 1.6, which is roughly consistent with empirical measurements for 1993-1996. In other words, the model predicts a period of low relative large-firm activity, which is consistent with observation. Moreover, the simulation projects this period to last about six years (see the estimated number of periods until innovation in Table 1), which corresponds closely with the data. The simulation now projects that industry concentration will decrease, and that the level of large-firm field trial activity will increase relative to SMURF field-trial activity. Empirical data and anecdotal evidence provides some tentative indications that this may be happening–for example, the rumored breakup/sale of Monsanto's agricultural units, but additional evidence needs to be gathered over the next few years before this prediction can be solidly confirmed. Nonetheless, the model behavior conforms quite well to the available data.

3. CONCLUSIONS

This paper is motivated by the cyclical pattern of R&D activity present in the agricultural biotech industry. An important component of this cyclical pattern is the co-movement of increases in industry concentration and the proportion of R&D trials carried out by large firms. This co-movement raise the question: Are large firms squeezing out small firms? Is this good for consumer welfare?

The model presented in the paper generates an explanation for the empirically observed movements of large-firm and SMURF R&D activity. In particular, the model behavior is driven by unexpectedly diminishing consumer acceptance of biotech-related products. The model generates cyclical patterns of large-firm R&D activity, but smoother patterns of SMURF R&D activity. These model behaviors are consistent with empirical observation. Examination of relative statistics, such as the number of genetically modified plant field trials, reveals a cyclical pattern that is caused by the cyclical pattern in large-firm R&D activity. This common pattern does not imply causality. In particular, the model clearly shows that SMURF R&D levels are unaffected by industry concentration in the large-firm industry, even in the presence of unanticipated shocks common to the SMURF and large-firm industries.

The policy implication is that existing data are insufficient to show that biotech concentration, driven by large firms, is negatively affecting the R&D investment of small firms.

This is a strong policy implication, driven by model assumptions concerning different behavior by SMURFs and large firms. The model does generate behavior consistent with existing empirical data, but detailed tests of the model and model assumptions are beyond the scope of this paper. Thus, verification/falsification of the behavioral assumptions is a promising area of future research. In particular, several empirical questions arise:

Do SMURFs really target niche crops?

Do large firms really target the high-potential crops to the neglect of niche crops?

What precisely is the relationship between innovative activity and the numbers of transgenic field trials?

Empirical confirmation that the answers to these questions are consistent with the model's assumptions would generate additional confidence in the policy implication.

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ENDNOTES

1. Mathematica© was used in the solution of most equations in this paper.